
Flight Testing the Fixed-Wing Configuration of the Rotor Systems Research Aircraft (RSRA)

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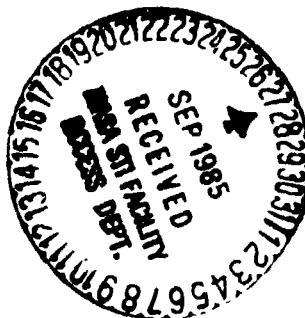
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SUMMARY

The Rotor Systems Research Aircraft (RSRA) is a unique research aircraft designed to flight test advanced helicopter rotor systems. Its principal flight test configuration is as a compound helicopter. The fixed wing configuration of the RSRA was primarily considered an emergency fly-home mode in the event it become necessary to sever an unstable rotor system in flight. While it had always been planned to flight test the fixed wing configuration, the selection of the RSRA as the flight test bed for the X-wing rotor accelerated this schedule. This paper discusses the build-up to, and the flight test of, the RSRA fixed wing configuration. It is written primarily from the test pilot's perspective.

FLIGHT TEST

The Rotor Systems Research Aircraft (RSRA) is a unique research aircraft designed specifically to flight test advanced helicopter rotors. The RSRA has flown as a helicopter, figure 1, and a compound helicopter (combination fixed- and rotary-wing aircraft), figure 2. This report describes the flight test of the fixed wing, or airplane configuration, of the RSRA.

The airplane configuration, figure 3, was originally considered primarily as an emergency fly-home mode in the event it became necessary to sever an unstable rotor system in flight. While it always had been planned to flight test the fixed wing configuration, the selection of the RSRA as the flight test bed for the X-wing rotor (currently being designed by Sikorsky Aircraft Company), made it desirable to accelerate these tests.

The X-wing rotor will be the first completely "new" rotor system to be flight tested on the RSRA. The helicopter version of the RSRA was delivered to Sikorsky Aircraft Company in May 1984 and is currently being configured as a compound helicopter with the X-wing rotor installed, figure 4.

The X-wing rotor is a four-bladed, nearly rigid rotor that generates lift and control by blowing air over leading and trailing edge coanda surfaces along the length of each blade. The rotor also has the capability to be stopped in flight, thus providing two swept forward and two swept back wings. The conversion from rotary to fixed wing and back to rotary wing is expected to occur between 180 and 200 knots.

The RSRA's variable incidence wing, control sharing capability, fly-by-wire flight control system, and performance envelope make it an ideal test bed for the X-wing rotor. In order to properly size the X-wing rotor, it was necessary to determine the basic control power for the fixed-wing RSRA to insure that it could overpower the sophisticated circulation-controlled X-wing rotor. While there were several objectives to the flight program, the primary one was to determine the basic stability and control of the fixed-wing RSRA in support of the X-wing program. The X-wing is expected to be flight tested on the RSRA in 1986.

The flight test objectives were:

1. Demonstrate the fixed wing configuration
2. Obtain fixed wing stability and control data in support of the NASA/DARPA X-wing program
3. Expand the aeroelastic flight envelope to 250 knots
4. Obtain rotor-off acoustics data
5. Obtain rotor hub drag data

The RSRA/X-wing configuration is expected to weigh approximately 33,000 lb and to have a very high center of gravity. It was important, therefore, to determine on the current RSRA fixed-wing configuration, the effect on stability and control, and aircraft handling qualities, of as high a weight and center of gravity as possible. To allow extrapolation to the RSRA/X-wing, two different RSRA airplane configurations were flight tested: one with the main rotor and hub removed, and the second with a weighted main rotor hub installed (minus blades). The latter configuration increased the aircraft weight 2,000 lb and raised the vertical center of gravity 7 in. The tail rotor remained on for all flight testing.

The Test Bed

Before one can fully understand the flight test approach to flying the fixed-wing RSRA, there are several unique features of the basic RSRA that require explanation. The RSRA was designed to allow the existing rotor to be removed and new advanced rotors of different numbers and lengths of blades to be installed. The RSRA has a full set of rotary wing and conventional aircraft controls, both of which can be operated either mechanically or through a fly-by-wire system. Provisions are made in both control systems to allow them to accommodate different rotor configurations.

Because of the increased number of control surfaces available in the compound configuration, a means of "control sharing" is incorporated in the flight control system. This is accomplished through a control phasing unit, or CPU, centrally located on the console between the two pilots. The CPU allows the pilot to select the proportion of his control inputs that will be made by the fixed- or rotary-wing control surfaces. This means the pilot can select full rotary wing, or full fixed-wing control, or any combination of the two. For example, the yaw CPU was used to keep rudder-pedal inputs from reaching the rotary rudder at speeds above 200 knots. Full fixed-wing and rotary-wing pedal inputs were used for all takeoff and landings. Even though the rotor blades were removed, the primary settings for the CPU were at the 100% fixed- and 100% rotary-wing position. This allowed the pilots to reduce the control gearing between the cyclic stick and the fixed-wing controls by making a small aft movement of the CPU levers. (The levers can be moved electrically or manually.) A mechanical stop was placed at the 75% fixed-wing control-input position to prevent an inadvertent washout of the fixed-wing controls.

The tail section of the RSRA contains a lower horizontal all-flying stabilator, an upper fixed horizontal tail plane, two large aft-mounted drag brakes, a conventional rudder, and a helicopter tail rotor. The aft-mounted drag brakes proved to be ineffective because of their limited opening angle.

The rotor transmission gear train and tail rotor are driven by two General Electric T-58 engines. Even though the main rotor was removed for these flight tests, it was necessary to operate both T-58 engines to drive the electric generators, hydraulic pumps, and tail rotor. The power plants which allow the RSRA to be flown as a fixed-wing airplane are two General Electric TF-34 high by-pass turbojet engines mounted on either side of the fuselage. In the compound helicopter mode, these engines had been derated to 6,250 lb thrust each. Prior to the fixed-wing flight test program, thrust was increased to 8,250 lb. During the ground operation to increase the thrust rating on these engines, an anomaly in the fuel system was discovered. In the RSRA, the left and right TF-34 and T-58 engines are fed from different fuel tanks. Each fuel tank includes an electric boost pump and uses the fuel bypass of the TF-34 engine to run an ejector pump which becomes the primary boost pump when the TF-34 is in operation, and the electric boost pump is turned off. With one TF-34 shut down, the strength of the ejector pump in the tank connected to the operating TF-34 engine overpowered the pressure from the electric boost pump in the other tank, resulting in the inability to crossfeed fuel from the tank of the shut down engine. Large fuel imbalances occurred during all single-engine operations. The fuel crossfeed problem was solved by providing pilot control of the interconnect valve between the two tanks. Any fuel imbalance could be corrected easily as long as the airplane was held in a nearly level flight attitude.

The throttles for the two TF-34 engines are two twist grips located on the collective controller. Since the collective cannot make an input without the rotor, it was mechanically locked at a comfortable position for the pilot. The throttles had been a major deficiency with the compound airplane and were deemed unsuitable for fixed-wing flying. High forces and a large hysteresis band made it virtually impossible to make small matched inputs to both engines simultaneously. For the

fixed-wing flight test, the existing throttle system was modified to include pneumatic boost servos from the U.S. Navy/McDonnell-Douglas F-18, resulting in a highly satisfactory throttle system. One readily adapts to making motor cycle grip inputs to the engines, although it is not recommended as a primary engine control concept.

The RSRA has a 45-ft wing which is unique because it can vary its angle of incidence from 9° leading down to 15° leading edge up. Wing incidence changes are made through two large hydraulic pistons attached to the leading edge of the wing. Control of wing incidence is provided through a handle on the center console between the two pilots.

Sled tests of the original extraction seats for the RSRA escape system indicated that the pilots could possibly be pulled through the tail rotor if they ejected at speeds above 188 knots. Thus, it was deemed necessary to replace the extraction seats with more capable ejection seats. The Martin Baker Mk US10LT ejection seat was selected. The overhead window and upper side railings were modified to provide window sill clearance for the pilots' knees on ejection. Since the Martin Baker seat operated on a hot gas system, and the rest of the extraction/rotor severance system operated on a pyrotechnic system, a suitable interface had to be built. Only two seats now exist in the RSRA. The flight engineer's position has been eliminated. The pilots' seats are restricted to pilots of 90 percentile or less.

Fixed-Wing Flight Test Concerns

There were several concerns regarding the fixed-wing flight tests: ground handling characteristics, the proper takeoff and landing techniques, and the unknown stall/spin characteristics of such an unorthodox configuration.

The ground handling characteristics were primarily influenced by the RSRA's:

1. Tail dragger configuration
2. High vertical center of gravity
3. High engine thrust line
4. High side force surface area
5. Low frequency directional control
6. Narrow gear
7. Undersized wheel brakes

The concerns regarding the proper takeoff technique centered around the selection of the proper wing incidence angle and flap setting that:

1. Allowed the wing to generate sufficient lift at an airspeed and angle of attack that did not require an excessive nose-down attitude during takeoff roll

2. Did not exceed the landing-gear stress limits

3. Required only a small fuselage rotation angle on lift-off to prevent the tail wheel from touching the ground

Tail wheel lift-off speed, predicted at 90 knots indicated, actually occurred between 75 and 85 knots. Unfortunately, the only airspeed calibration data we had was from the compound configuration. The influence of the rotor was a major factor in the airflow in and around the pitot static system. Ground radar tracks and static pressure changes during the high-speed taxi tests indicated an airspeed calibration factor of plus 10 knots. This was consistent with the compound configuration. Inflight calibrations showed that a plus 17 knot correction was a more realistic number.

The landing technique required the selection of a wing incidence angle and flap setting that allowed the airplane to be flown at a reasonable airspeed margin above the stall, resulted in neither too much of a nose down attitude at landing, nor a high enough pitch attitude that the tail wheel touched down first. It had to be decided whether a wheel landing or near stall three-point landing would be best. Directional control and braking during landing roll out were also of concern.

In up-and-away flight there were several concerns:

1. Unknown stall/stall-spin characteristics

2. High speed/tail rotor interaction

3. Relatively high wing loading

The build-up to the fixed-wing flight tests included analytical studies, ground simulation, and compound flight tests.

Flight Simulation Program

The NASA Ames Flight Simulator for Advanced Aircraft was used to investigate various takeoff and landing techniques at different wing incidence angles and flap settings. Even though the confidence in the runway/airplane modeling was not great, the techniques developed in the simulator were directly transferable to the actual flight environment. The simulator also proved invaluable in the investigation of the possible stall/stall spin characteristics of the airplane. Consultation with the spin experts at NASA Langley indicated that very little stall/spin information existed for airplanes with a vertical center of gravity or a side force area as high as the RSRA. Wind tunnel data indicated that stall speed also varied as a function of wing incidence angle, increasing almost linearly (1 knot per degree of wing incidence) to a maximum at $+15^\circ$. This phenomenon is attributed to the increased fuselage lift at the lower wing incidence angles. NASA Langley recommended that the

fixed wing airplane not be flown to stall because of the unknown spin characteristics. Since it was not necessary to fly at these low speeds, the airplane was restricted to 15° wing angle of attack or 115 knots indicated, whichever occurred first. The simulator showed that the airplane would stall conventionally and showed little propensity to spin. However, there was limited confidence in the simulator modeling at the high angles of attack.

It was concluded from the simulator that a 5° wing incidence angle and a flap setting of 15° provided an acceptable takeoff attitude at a rotation speed of 125 knots. Full flaps (25°) and the same 5° wing incidence angle were selected for landing. The best landing technique seemed to be to make a wheel landing from an approach speed of 140 knots to a threshold speed of 125 knots with touchdown occurring around 115 knots. The visual cues in the simulator made it somewhat difficult to accurately judge the height above the runway for touchdown. Both pilots bounced and PIO'd their share of simulator landings.

The simulator confirmed the analytical prediction of a degradation in control surface effectiveness as the aircraft weight and vertical center of gravity were increased, but indicated that it would still be an acceptable airplane to fly.

Compound Flight Tests

The compound configuration was used to investigate the lift and stall characteristics of the wing. Near zero lift was obtained on the RSRA rotor, and the fixed-wing angle of attack was increased to stall. As the wing stalled, lift was rapidly transferred from the wing to the auto rotating rotor. A rapid increase in rotor rpm became the best way to determine when the wing stalled. The wing, fuselage, and empennage area were extensively tufted. Photo coverage showed that the stall progressed in a classic manner for a straight winged aircraft. The root of the wing stalled first, although there was little or no noticeable stall warning that could be felt in the cockpit. Increasing the collective setting to the rotor was a rapid and positive way to decrease the angle of attack on the wing.

The compound configuration was also used to evaluate the transfer of pilot control inputs from a combination rotary- and fixed-wing input to fixed-wing only inputs. Pilot control inputs were incrementally washed out to the rotary wing by advancing the control phasing unit lever to the full fixed-wing input position. The airplane was sluggish but quite controllable.

Following the simulation and compound flight tests, the airplane was ferried in the compound configuration from NASA Ames Research Center at Moffett Field, California to the Dryden Flight Research Facility at Edwards AFB, California.

High Speed Taxi Tests (Fixed wing)

Following removal of the main rotor head and blades, modifications to the complex instrumentation system and a redesign of the left landing gear door (which

failed in flight during the compound flight tests), the airplane was ready for high-speed taxi tests.

The purpose of the high-speed taxi tests was to evaluate the following items:

1. Ground handling characteristics
2. Braking capability
3. Tail wheel lift-off speed
4. Ground simulator results for proper wing incidence and flap settings for takeoff
5. Airspeed calibration
6. Tendency to become airborne

The fixed-wing RSRA embodies all the characteristics not to build into a tail dragger airplane if you want to reduce its tipover and ground looping tendencies. The high center of gravity, high-thrust line, high side force area, and narrow gear, when coupled with low frequency directional control, caused considerable concern during the ground handling of the airplane. The primary reason for keeping the tail rotor on the airplane was to assist in ground handling and to reduce the engine-out speed of this multiengine airplane. The high-speed taxi tests indicated that, while not particularly good, the ground handling qualities were acceptable. It was decided, however, to limit flying the airplane to crosswinds of less than 15 knots, in the lower weight and lower center of gravity configuration, and to 10 knots, at the higher weight and higher center of gravity.

The taxi tests confirmed the 5° wing incidence and 15° flap setting for the lighter weight configuration. Because of the rapid acceleration of the airplane, TF-34 power settings had been limited to 70% fan speed or less during the ground taxi tests. At the lighter weight, the thrust-to-weight ratio is approximately 0.7. The tail wheel came off the ground between 75 and 85 knots.

Calculations had shown that the wheel brakes on the RSRA could overheat severely if full braking was used to stop the airplane from 120 knots. Direct reading brake temperature gages were stalled in the cockpit and proved highly beneficial. As the brakes do not have antiskid protection, it was imprudent to apply the brakes above about 90 knots; by observing this limit, the overheat problem never materialized. The right TF-34 is shut down during ground roll-out to reduce stopping distance.

The last task of the high-speed taxi tests was to check for the tendency to become airborne before the tail wheel touched the ground. The intent was to keep the aircraft on the runway but light on the wheels. The combination of a light airplane, a 7 knot difference between the actual and indicated airspeed calibration, and (most probably) an overzealous pilot, the airplane became airborne twice during the high-speed taxi tests. The first time it reached an altitude of about 25 ft;

the second airborne attempt was only a couple of feet off the runway. The lesson learned was: always be fully prepared to fly during any ground taxi test.

Flight Tests (Fixed Wing)

The high-speed taxi tests confirmed that an indicated airspeed of 125 knots, with the wing set at 5°, and the flaps at 15°, allowed the airplane to become airborne before the tail wheel touched the ground.

A maximum TF-34 fan speed of 80% was established for the first flight take-off. On takeoff roll, the copilot calls out fan speed as the pilot manipulates the two throttles as the airplane accelerates down the runway. The difficulty matching engine power compounds the directional control problem.

The takeoff weight for the first flight was approximately 1500 lb heavier than for the takeoffs which occurred during the taxi tests; consequently, the airplane was considerably slower coming off the runway. At lift-off there was a tendency to over control the airplane in pitch. From the cockpit it was almost impossible to tell if the tail wheel touched the ground on lift-off. Ground movies later showed that it did not touch, but with the heavier airplane, a greater attitude change was required to fly. Climb performance was impressive--even with only 80% fan speed.

Climbout was made at 150 knots. After the gear and flaps were retracted, it was obvious that the airplane had a noticeable shuddering or shaking in the vicinity of the tail, and that there was a longitudinal chugging that occurred at irregular intervals.

The airplane rapidly reached 7,800 ft (10,000 ft density altitude) and leveled off at 150 knots. All flights were flown at 10,000 ft density altitude because of tail rotor. The longitudinal chugging stopped at level off, but shaking in the tail area continued. The structural engineers indicated that some endurance limits were occasionally being exceeded, but that it was not a major concern.

One possible cause of the shaking was a flight control input through the stability augmentation system (SAS). The SAS was turned off incrementally (there are four SAS channels) without any change in the shaking. The next step was to change the wing incidence angle to see if the flow over the horizontal tail could be changed. Wing incidence was increased from 5° to 7-1/2° which brought no change in the aircraft response. One last thought was to lower the flaps. Flaps were extended to 15° and the shaking stopped almost immediately. The flaps were raised in increments; setting the flaps at 5° stopped the shaking. The rest of the flight program was flown with the flaps extended 5°. The brevity of the flight test program did not allow further exploration of this phenomenon.

Up-and-away, the airplane was quite stable, very similar to a medium weight cargo type airplane. There was a slight tendency for the airplane to feel like it would slide laterally. This was later attributed to poor matching of TF-34 power.

At 150 knots, the control sensitivity was low and the damping high in all axes. Control-sensitivity increased with speed, becoming quite sensitive above 180 kts.

The tail rotor was the limiting factor on the maximum speed that could be attained. It was necessary to keep the tail rotor tip speed below Mach 1, this was accomplished by reducing tail rotor rpm to 94% and limiting the maximum speed of the aircraft to 250 knots. To further reduce structural loads on the tail rotor, above 200 knots rudder pedal inputs were prevented from reaching the tail rotor, by moving the yaw control phasing unit to the full fixed-wing position, and sideslip was restricted to less than $7\frac{1}{2}^\circ$. The tail rotor rpm was quite stable even though the T-58 engines were operating at only 5% to 10% torque.

An important event on the first flight was to check the structural soundness of the left landing gear door that had been redesigned following an inflight failure during the compound flying. It also provided the first look at the RSRA handling qualities in the landing approach configuration. The gear and flaps were extended and data records were taken in increments from 140 to 160 knots indicated air-speed. The door redesign proved satisfactory.

The next task was the landing. Ground simulation had indicated that a wheel landing would probably be the best landing technique. The two landings during the two airborne portions of the high-speed taxi tests showed that either a three point or wheel landing was possible. After two low approaches to the runway, it was determined that the airplane flew nicely at a 140 knot approach speed and was easily controlled down to 120 knots. The planned touchdown speed was near 115 knots.

On landing, the airplane seemed to float more than expected. A small power reduction caused the airplane to touchdown in a slight right crab at about 112 knots. Forward stick converted what the ground movies would later show was a three point landing into a wheel landing. It was one of the better landings of the program. On subsequent flights, attempts at making three point landings invariably resulted in landing tail wheel first with a heavier impact on the main gear than was desired. The combination of a light airplane and very stiff landing gear often resulted in a two or three oscillation pitch bobble right after touchdown. It seemed independent of whether a wheel or three point landing was attempted.

Once on the ground almost all attention was devoted to controlling the airplane directionally. The shutdown of the right TF-34, while required to reduce landing distance, aggravated the directional control problem. After several flights, total landing distances as low as 5500 ft were demonstrated. Stopping distances of 2500-3000 ft were required.

Most of the up-and-away flying was devoted to the primary task of determining the control power available for each control axis. Most of the performance data were obtained during the envelope expansion flights. Stability data were obtained from sine wave and a set of specially designed combination step-and-doublet inputs. An anomaly noted during the stability tests was that the airplane exhibited a different response for nose-up and nose-down inputs. Nose-down inputs tended to appear uncoupled from the roll axis while nose-up inputs always resulted in a roll

to the left. It is believed that this is caused by air flow interaction with the tail rotor.

On two different flights, the airplane experienced a failure of the leading edge fairing on the right wing fillet. The first time the upper half of the fairing was lost, and the second time it peeled back, but did not leave the airplane. A redesign using fiberglass rather than metal for the fairing ultimately solved the problem.

To accomplish the primary objective of the program (getting data that could be extrapolated to the RSRA/X-wing configuration), 2000 lb of weight was added to the main rotor hub and the hub then installed on the airplane. This installation increased the aircraft weight to 28,000 lb and raised the vertical center of gravity 7 in. The aircraft was weighed before and after each flight until sensitive fuel totalizers installed in the fuel system were calibrated.

It had been anticipated that disturbed air off the rotor head would impinge on the upper horizontal tail, but that it would be no greater than what had been experienced during the compound flying. Unfortunately, the airflow disturbed the tail area at a very uncomfortable frequency for the flight crew. Tail motion was also visible to the chase pilot. Stress levels were borderline to endurance values but considered acceptable. The first flight, however, was terminated early. Various wing incidence angles and flap settings were tried, but no flight configuration could be found that eliminated the structural vibrations. It was decided to fly this configuration only enough to obtain sufficient control power data to allow extrapolation to the higher gross weight anticipated for the RSRA/X-wing configuration.

Having the rotor hub on the aircraft provided a unique flight test opportunity. With the variable incidence wing, aircraft pitch attitude could be changed while maintaining the same airspeed and altitude. This allowed a complete set of pure rotor hub drag data to be obtained by comparing the drag of the RSRA with and without the main rotor hub installed.

Acoustics data were obtained from an acoustics array located on the dry lakebed at Edwards AFB. Noise signatures were recorded for several airspeeds and rates of descent.

CONCLUSIONS

The fixed-wing flight test program completed the flight demonstration of the three configurations of the RSRA: helicopter, compound helicopter, and fixed-wing airplane.

It was demonstrated that the RSRA fixed-wing performance and handling qualities are adequate for a safe "fly-home" mode should it become necessary to sever an unstable rotor system from the compound RSRA.

This flight test program provided invaluable data for the design and flight test efforts of the RSRA/X-wing aircraft.

It was concluded that the fixed-wing RSRA is an acceptable flight test bed for the X-wing rotor.

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Figure 1.- The RSRA helicopter configuration.

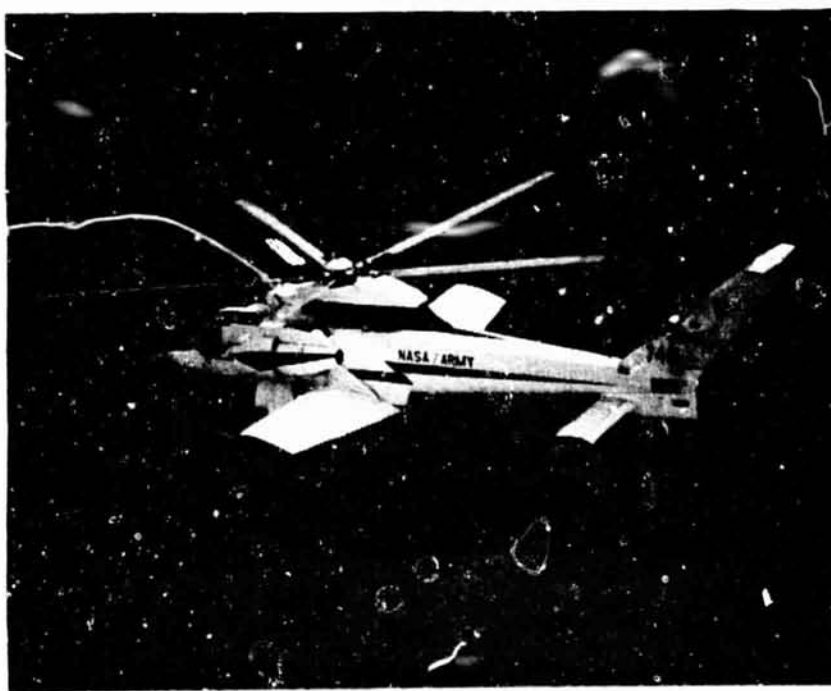


Figure 2.- The RSRA compound configuration.

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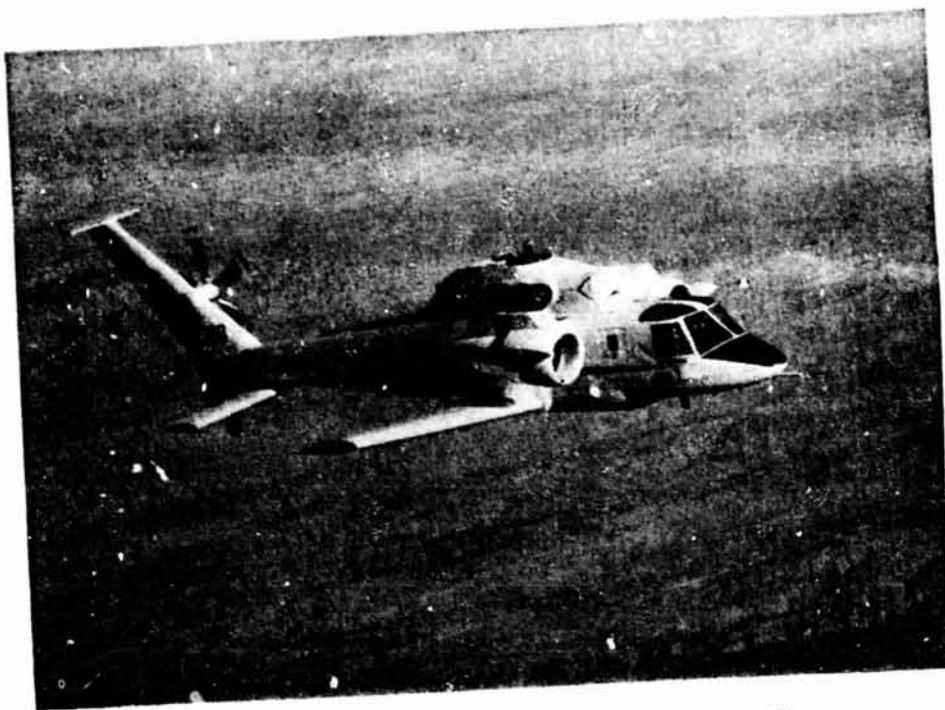


Figure 3.- The RSRA fixed-wing configuration.

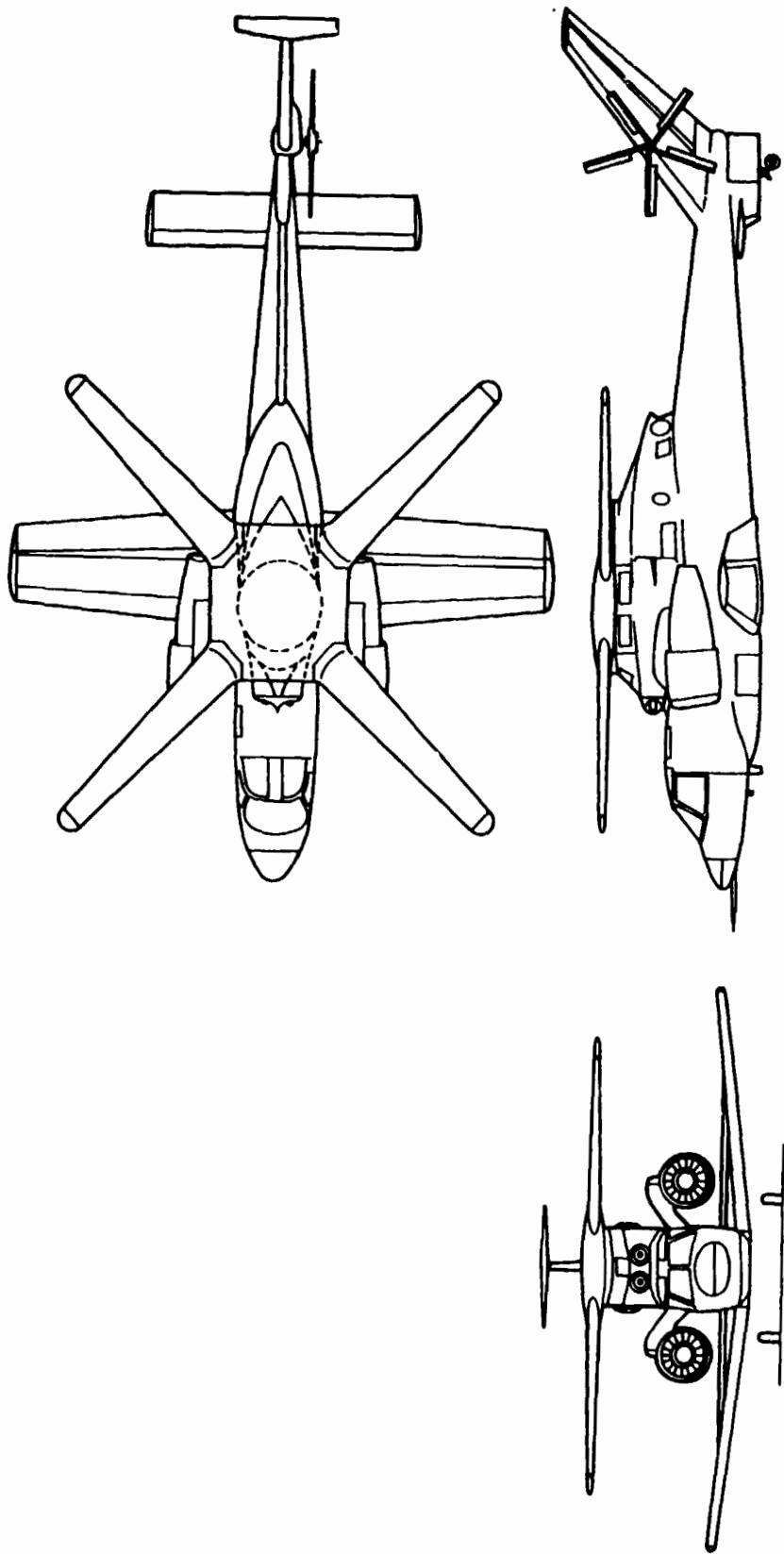


Figure 4.- Artist conception of the RSRA/X-wing configuration.

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